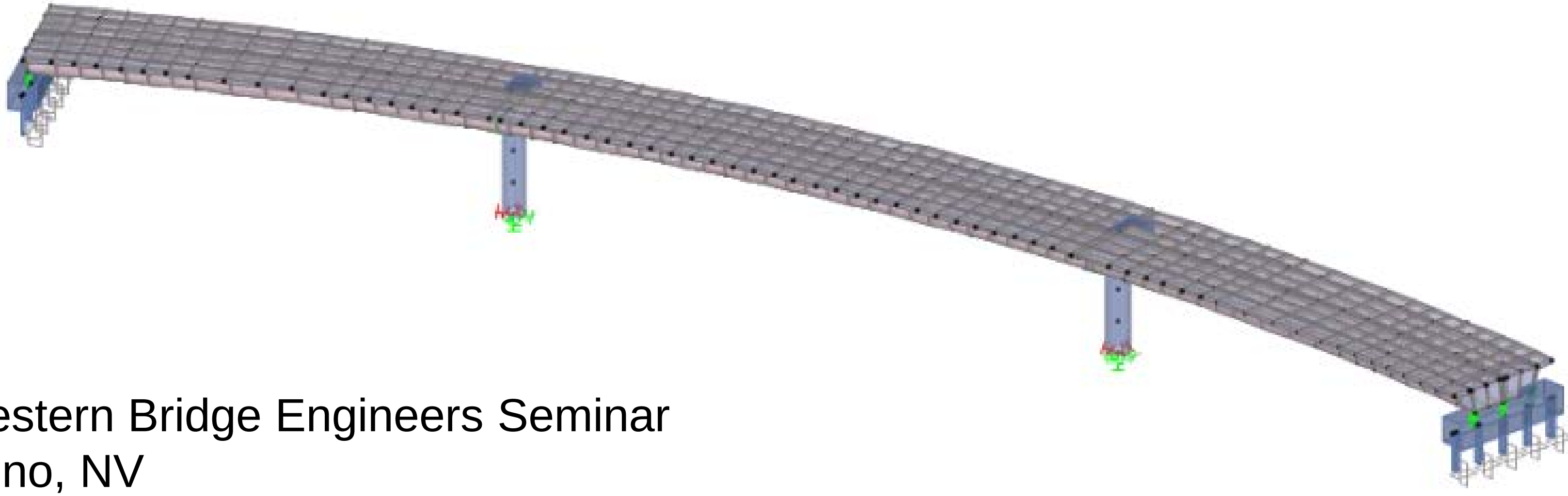
Plastic Hinging Considerations for Single-Column Piers Supporting Highly Curved Ramp Bridges



Western Bridge Engineers Seminar
Reno, NV

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September 10, 2015

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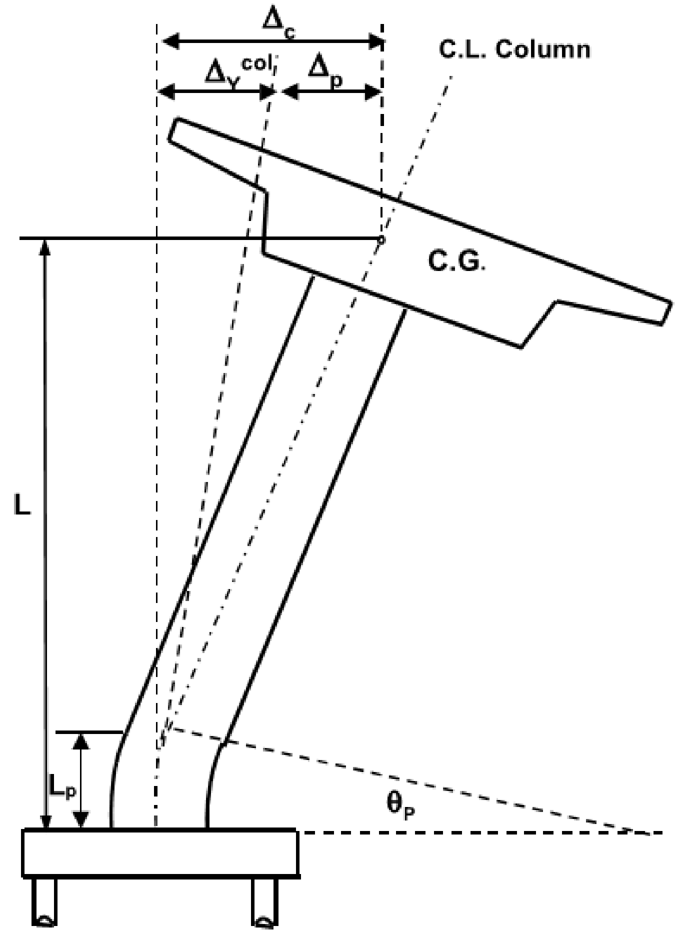
Overview

- Typical Straight Ramp Bridge Hinging Locations
- Possible Curved Ramp Bridge Hinging Locations
- Any Need for Concern?
- Fixed Bridge Response
- Drilled Shaft Foundations
- Pile Foundations
- Other Design Considerations

Typical Straight Bridge Hinging Locations

- Typically modelled as a "flag pole" in transverse direction
- Bottom of column hinge location typical
- Assume superstructure has negligible torsional rigidity



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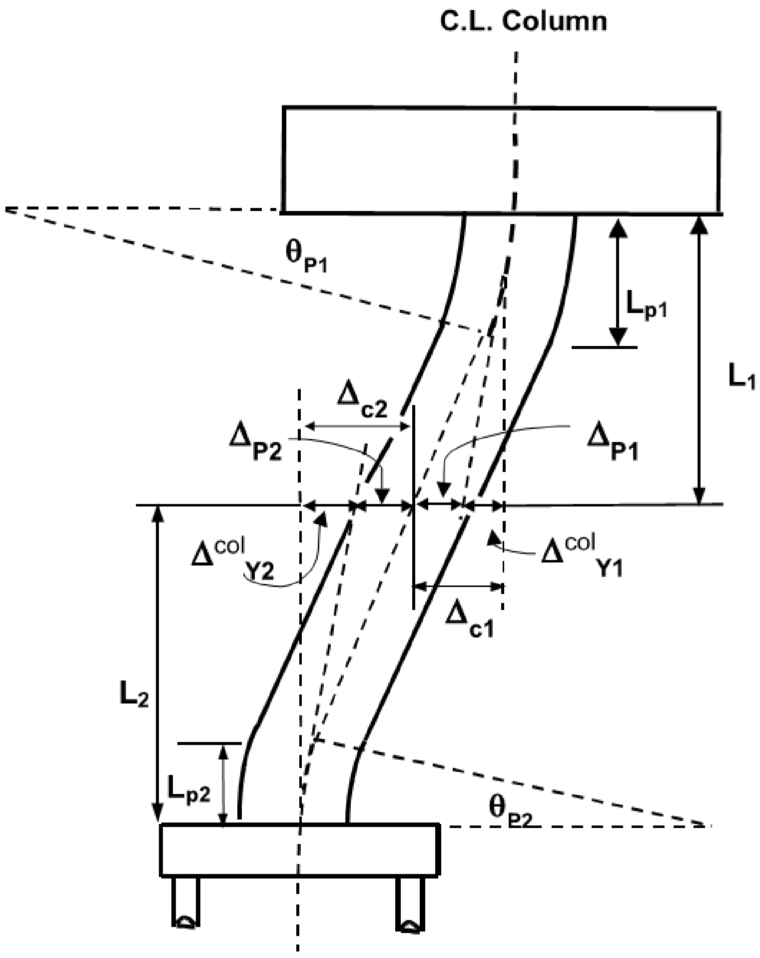
Possible Curved Bridge Hinging Locations

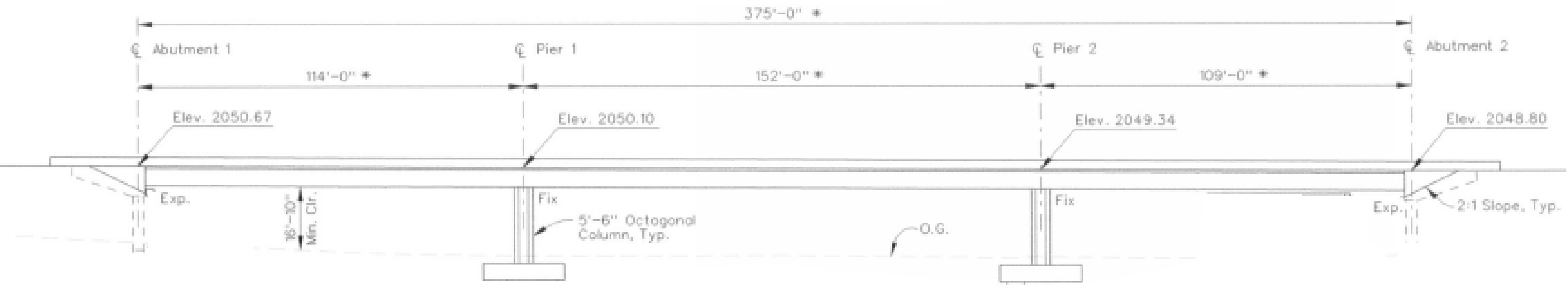
- **Torsional rigidity in addition to longitudinal coupling of superstructure stiffness increases top of column rigidity**
- **Can create reverse curvature**
- **Hinging possible at top and bottom of column**



Any Need for Concern?

- **The answer is <u>YES!</u> if no hinging is expected from longitudinal EQ**
- **Due to hinging the top of the column, the shear force will approximately double as compared to a column in single curvature.**
- **Confinement details may not be provided at top of column.**
- **Column vertical reinforcement may not have proper development into crossbeam.**
- **<u>CONCLUSION:</u> The above items could lead to unintended column performance although the structure met current seismic design requirements.**

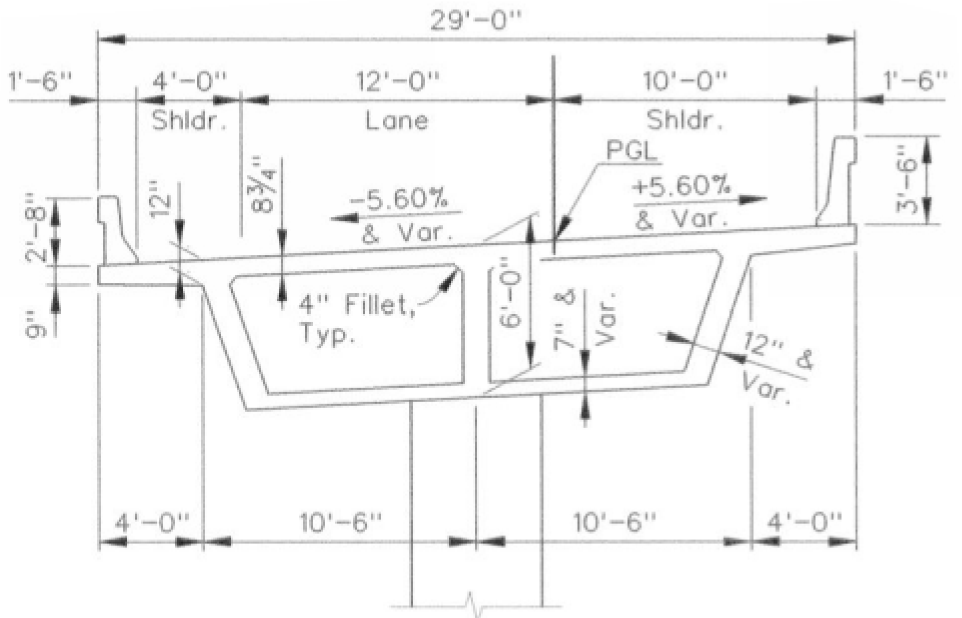
Example Bridge – CIP Box Girder



Variations Considered

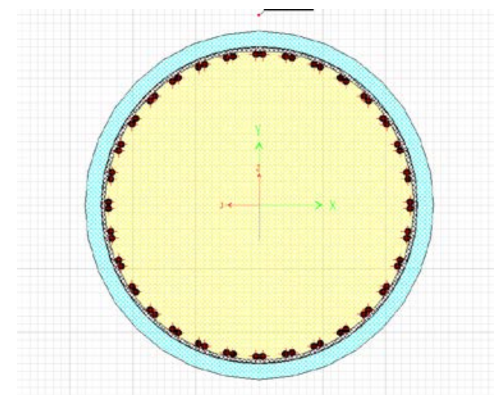
- **Curve Radii: 1000ft, 800ft, 600ft**
- **Foundation Types: Fixed, Drilled Shaft, Piles**

Example Bridge – Typical Sections



Typical Section

- f'_c = 4 ksi (all concrete)



Typical Column Section

- 5ft – 6in Diameter
- 64-#10 bars (2.4%)
- #6 spiral @ 3 ½ in pitch

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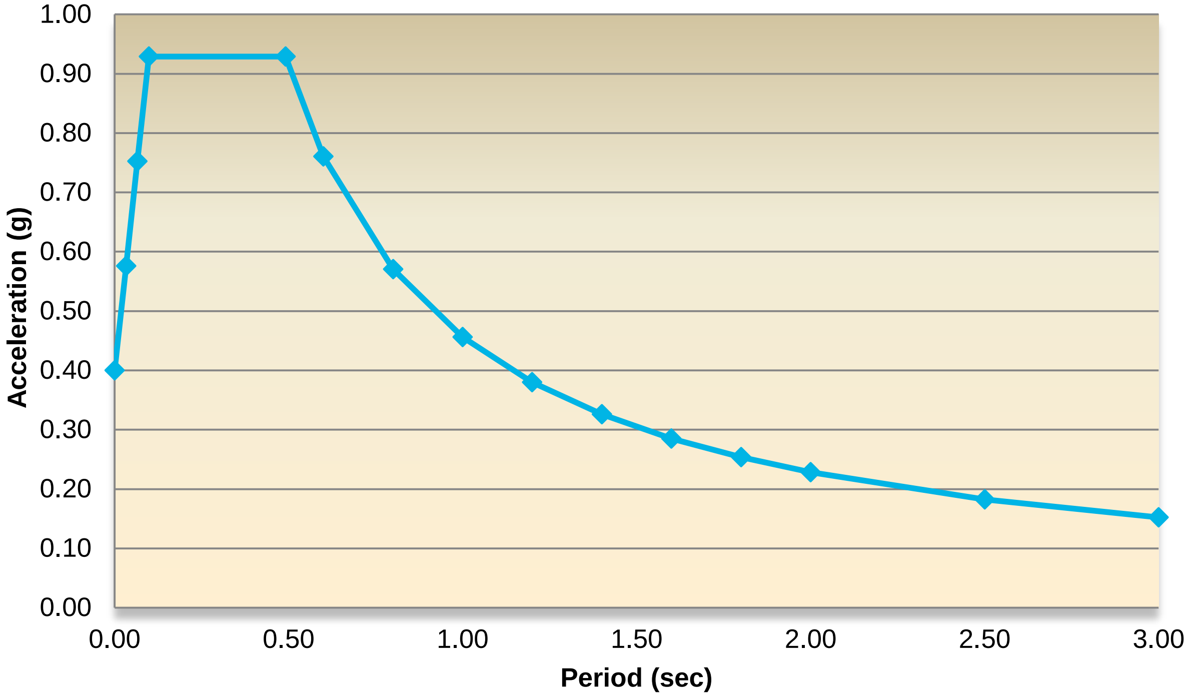
Example Bridge – Response Spectrum



- **Peak bedrock ground acceleration, 0.4g**
- **0.2 Sec Acceleration, 0.89g: 1.0 Sec Acceleration, 0.30g**
- **Seattle area, Site Class "C"**

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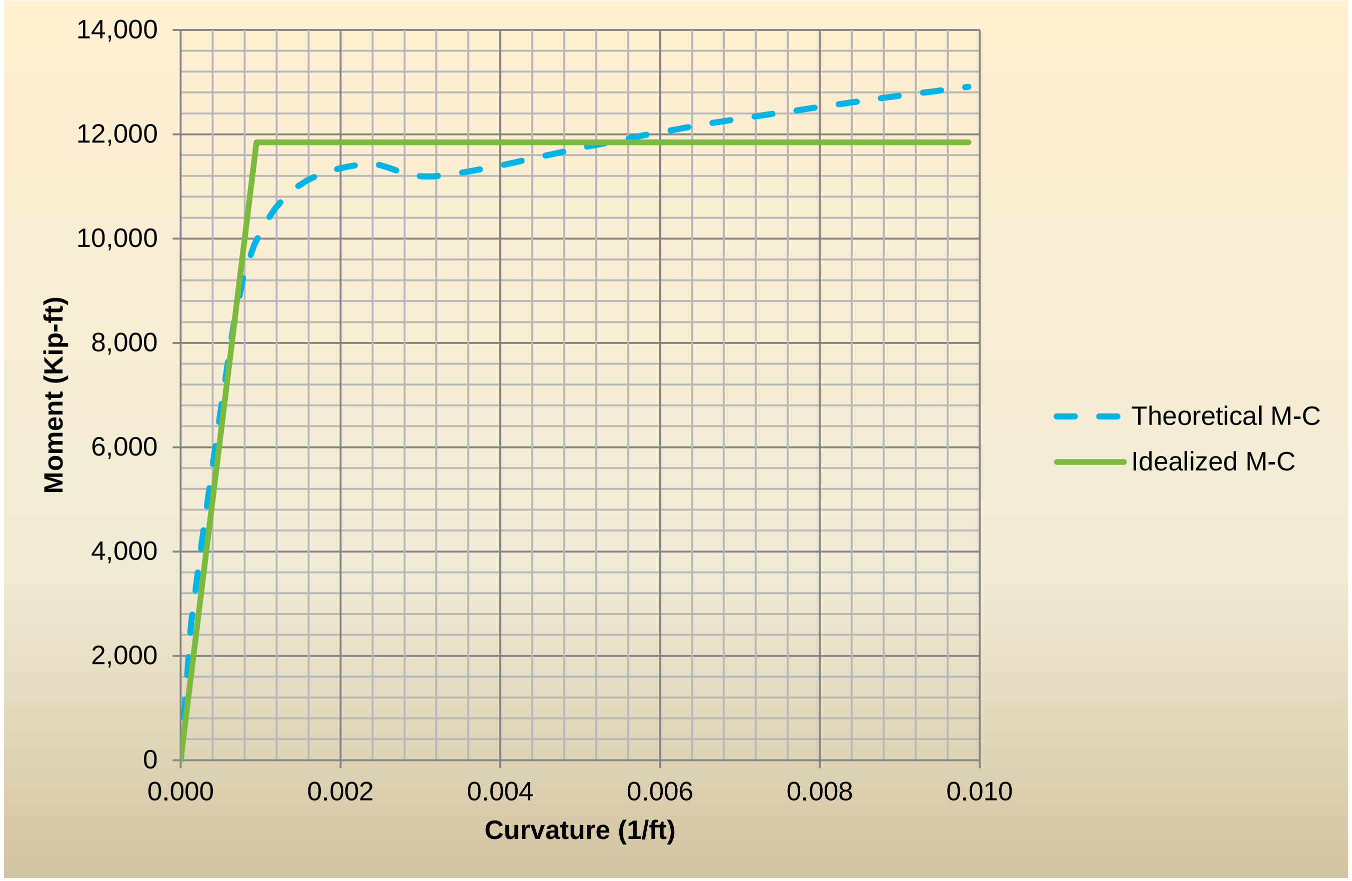
Moment Curvature Plot



- **Axial Load = 1,300 kip**
- **Used expected material properties**

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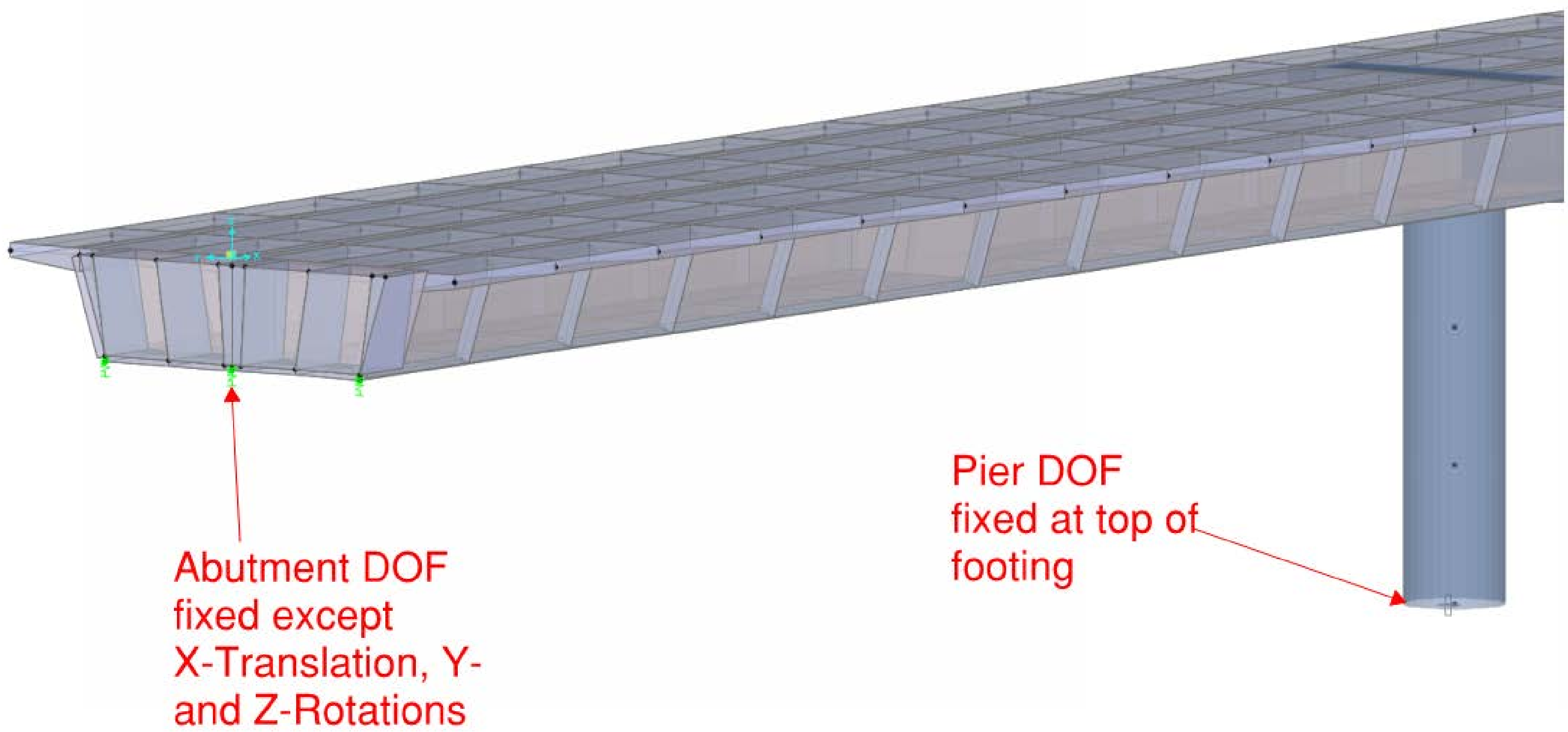
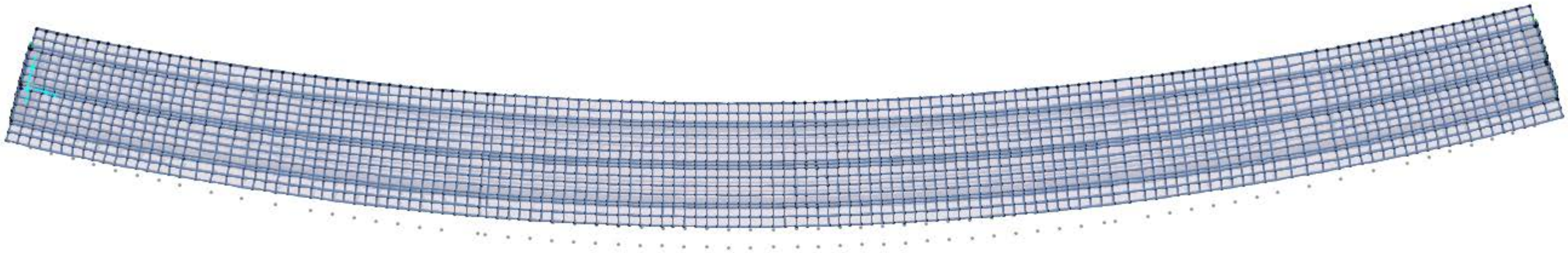
Fixed Based Model



First Mode: T = 0.49 sec



- **Mode Participation Factor = 0.7080**

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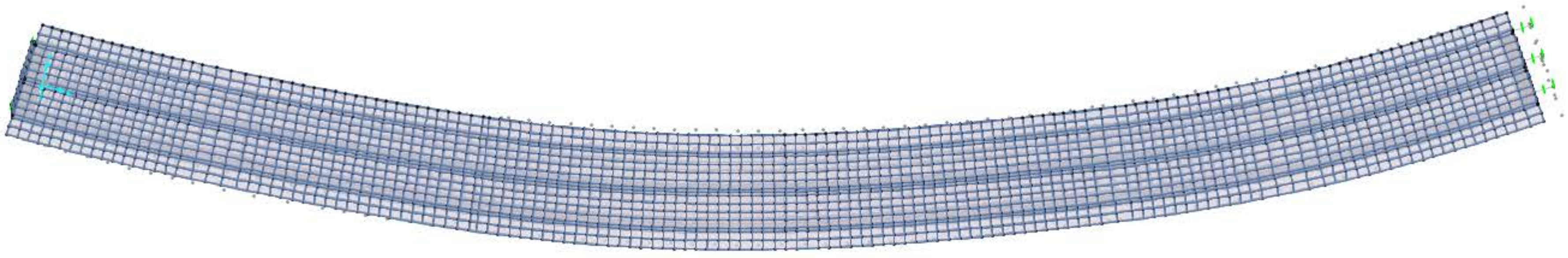
Second Mode: T =0.42 sec



- **Mode Participation Factor = 0.1301**

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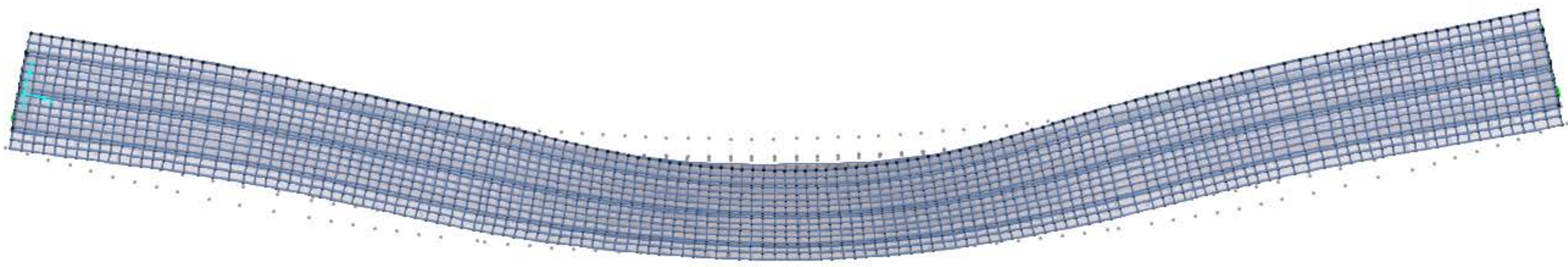
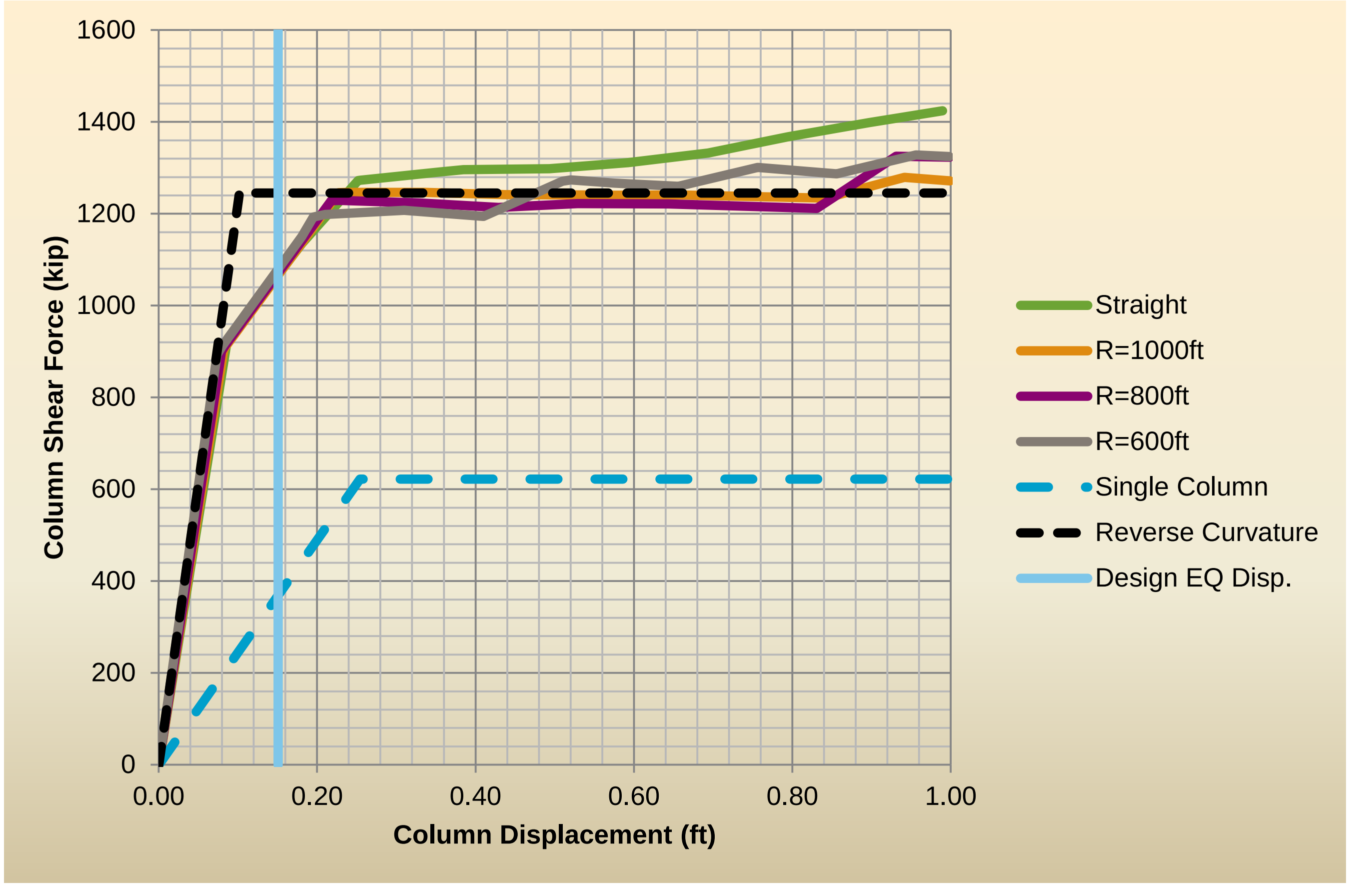
Seventh Mode: T = 0.13 sec

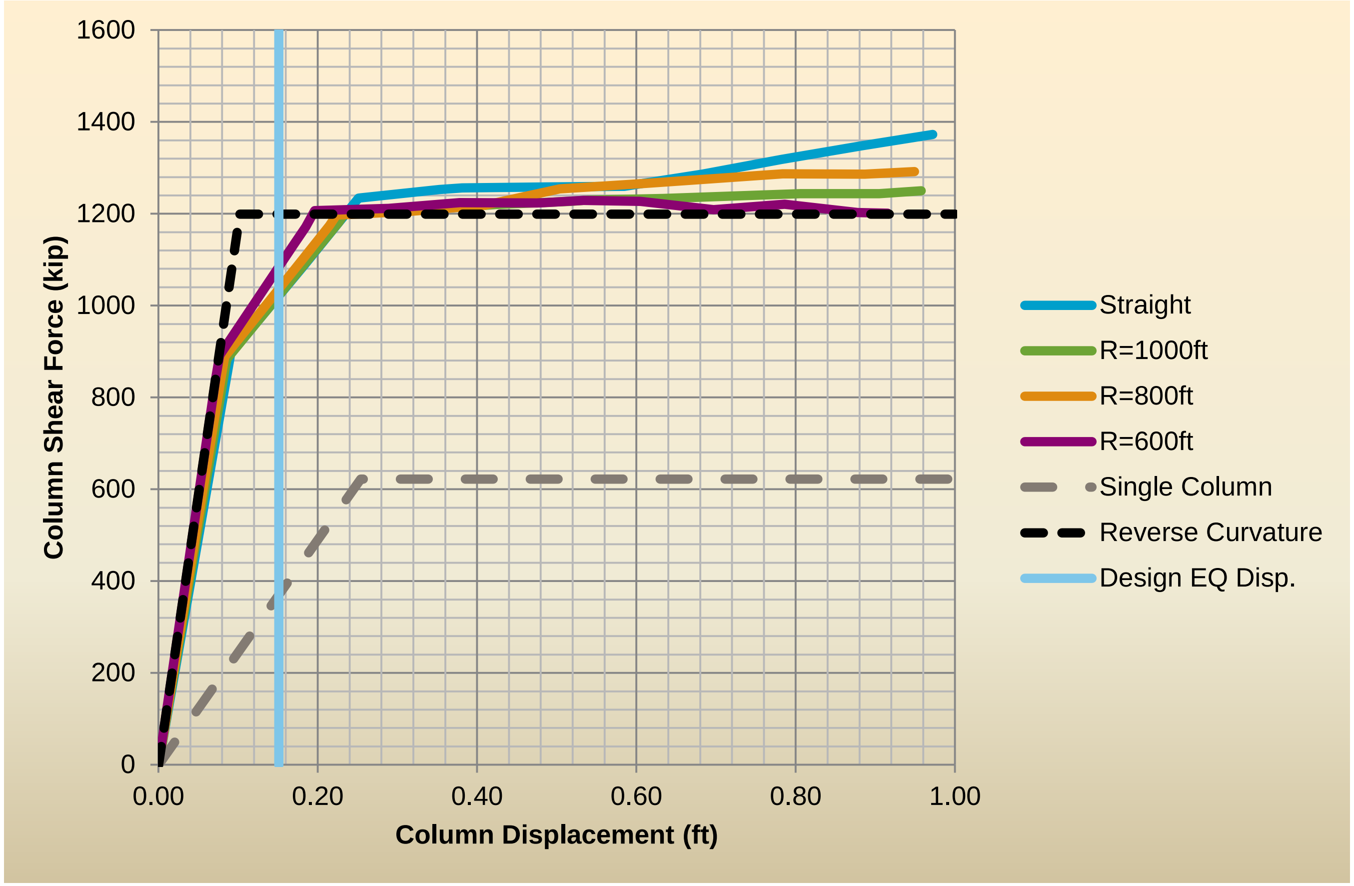


- **Mode Participation Factor = 0.1618**

Fixed Based Response – Pier 1



Fixed Based Response – Pier 2



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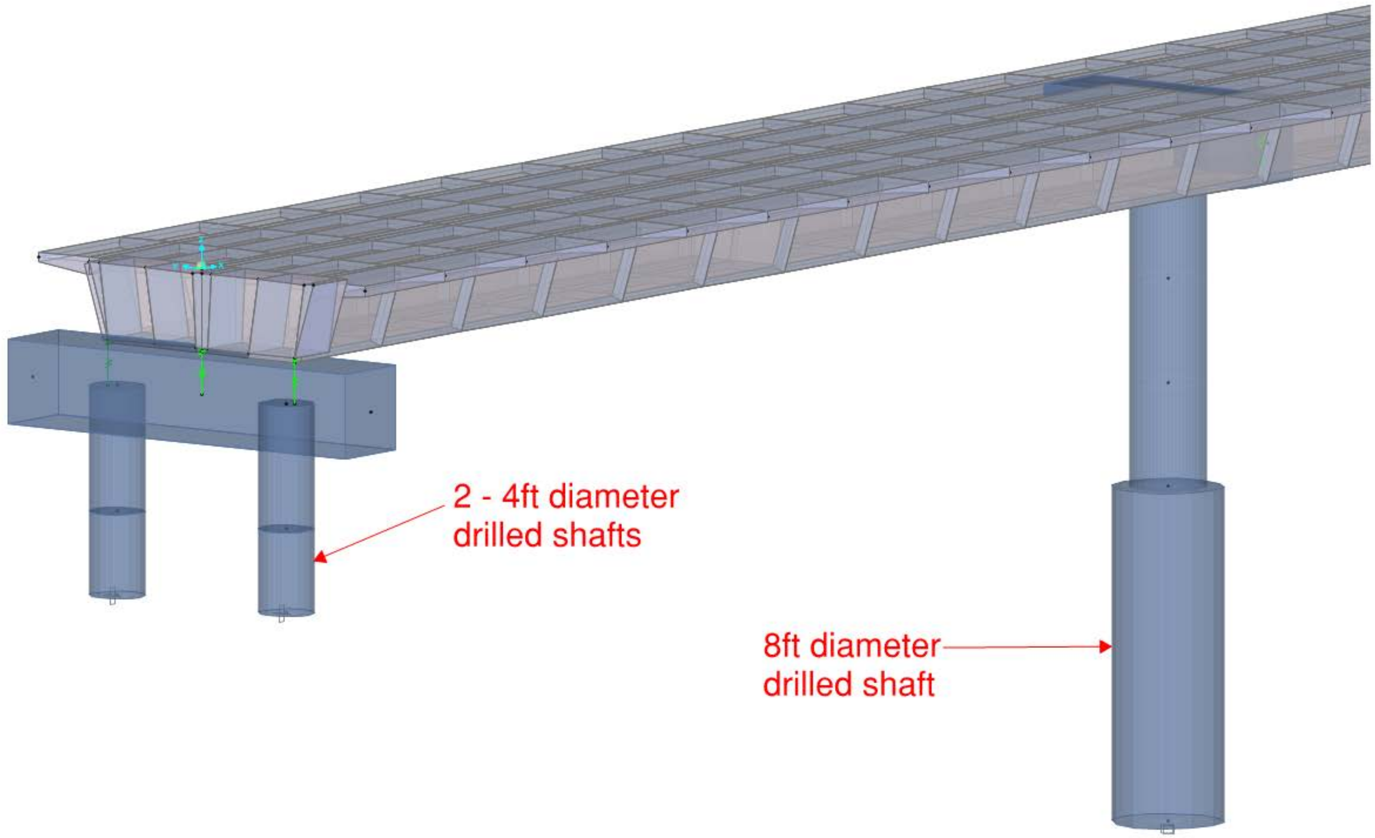
Drilled Shaft Model



- **Depth to fixity assumed to be 3 shaft diameters**

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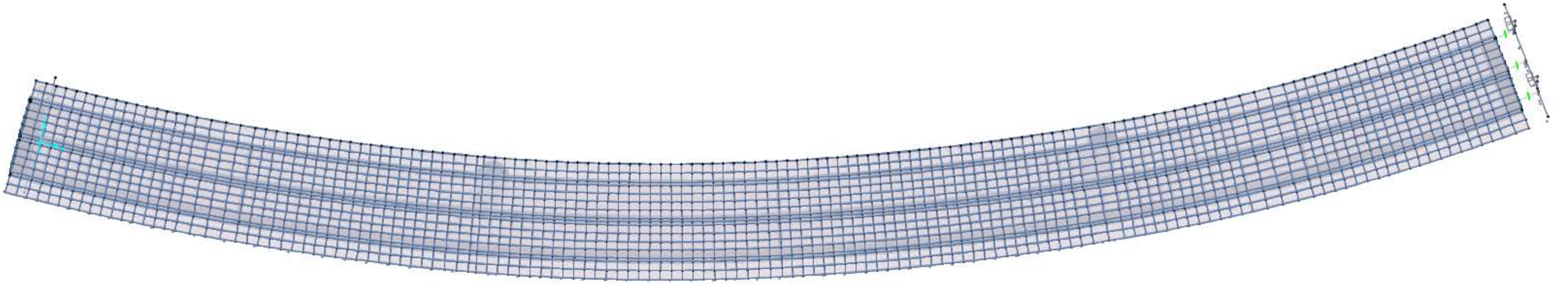
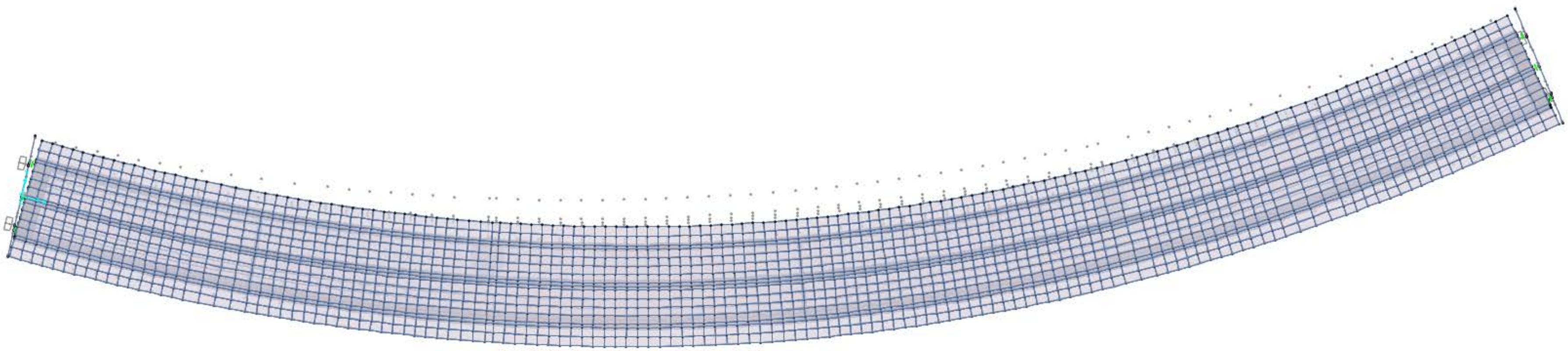
First Mode: T = 0.68 sec



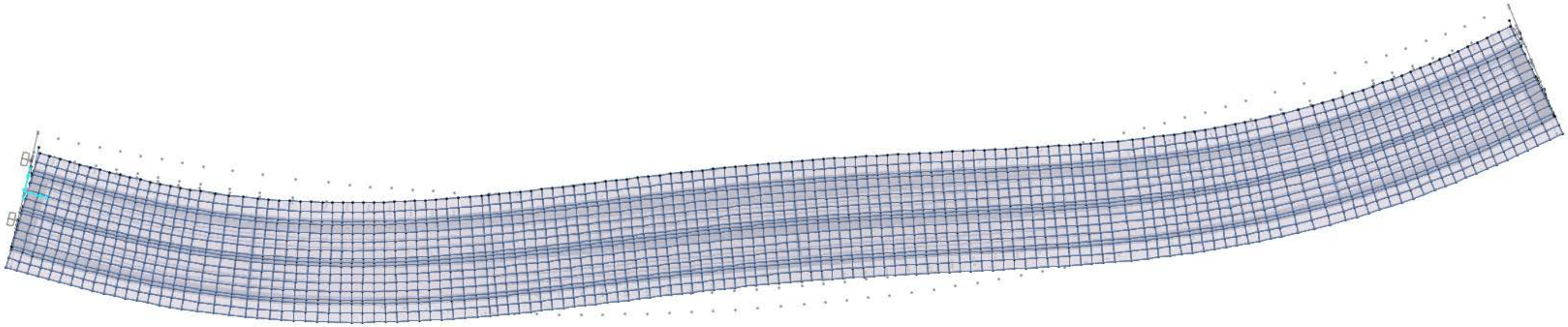
- **Mode Participation Factor = 0.0639**

Second Mode: T = 0.67 sec



- **Mode Participation Factor = 0.7357**

Seventh Mode: T = 0.16 sec



- **Mode Participation Factor = 0.2034**

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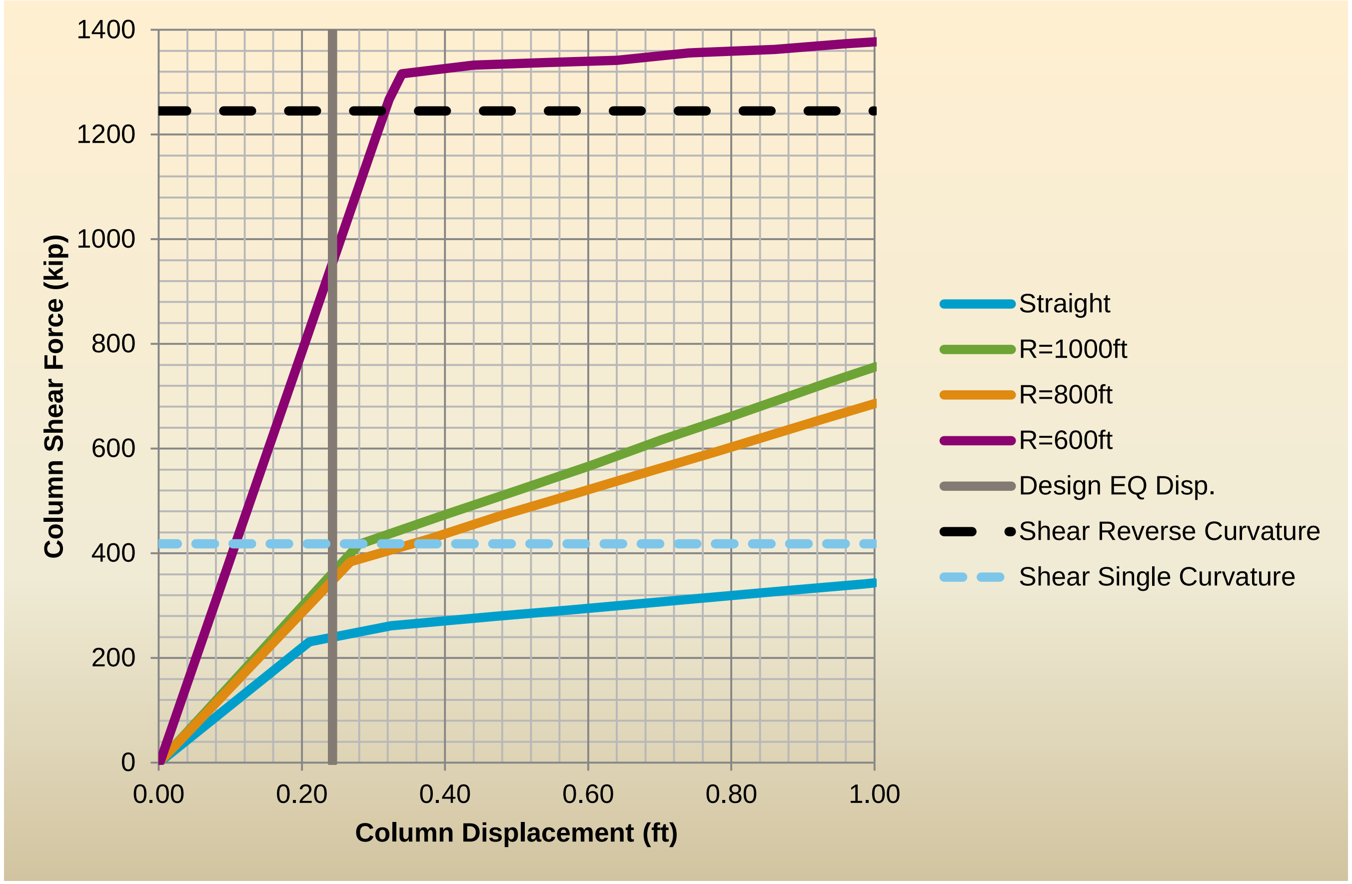
Drilled Shaft Response – Pier 1



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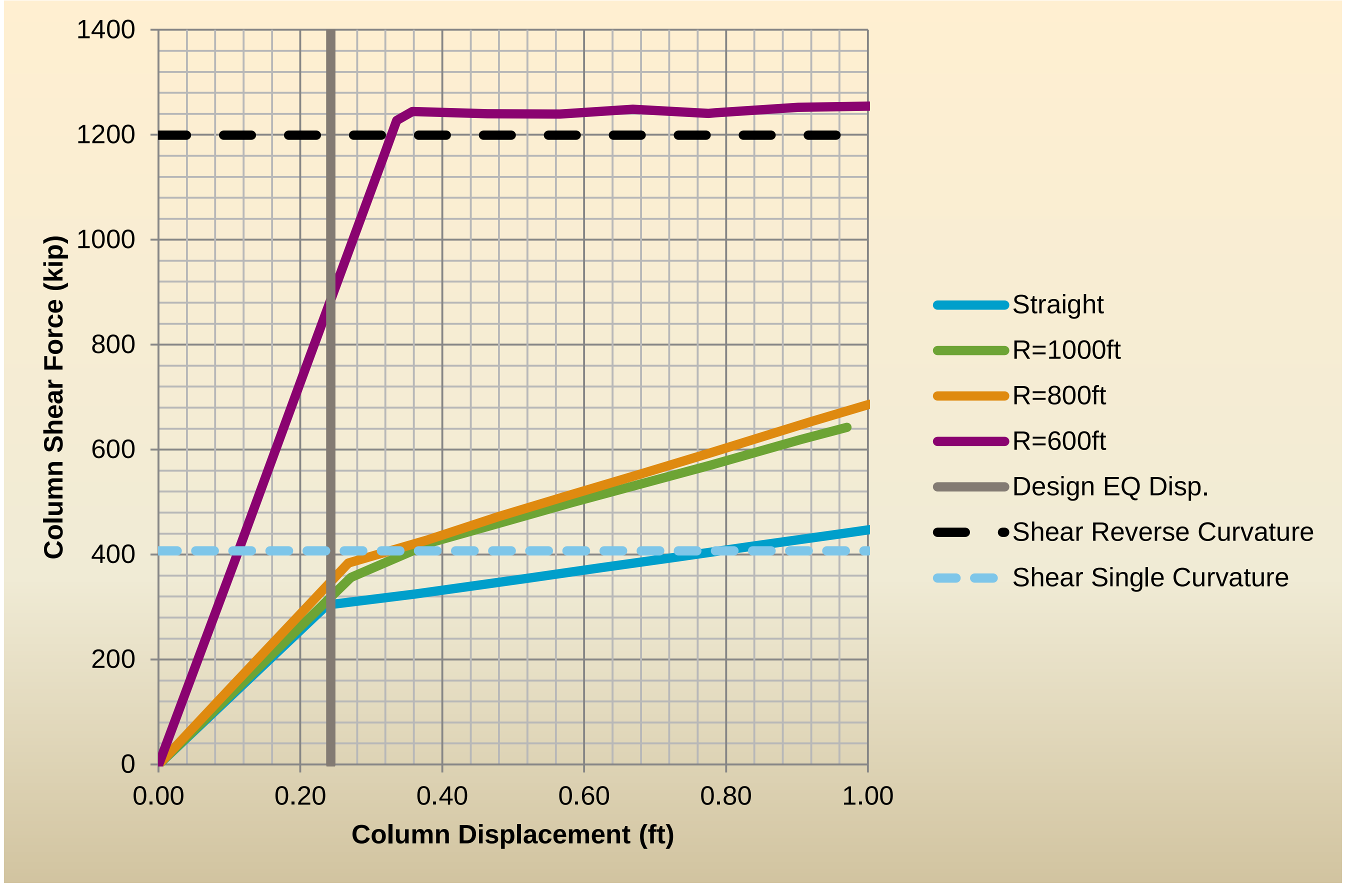
Drilled Shaft Response – Pier 2



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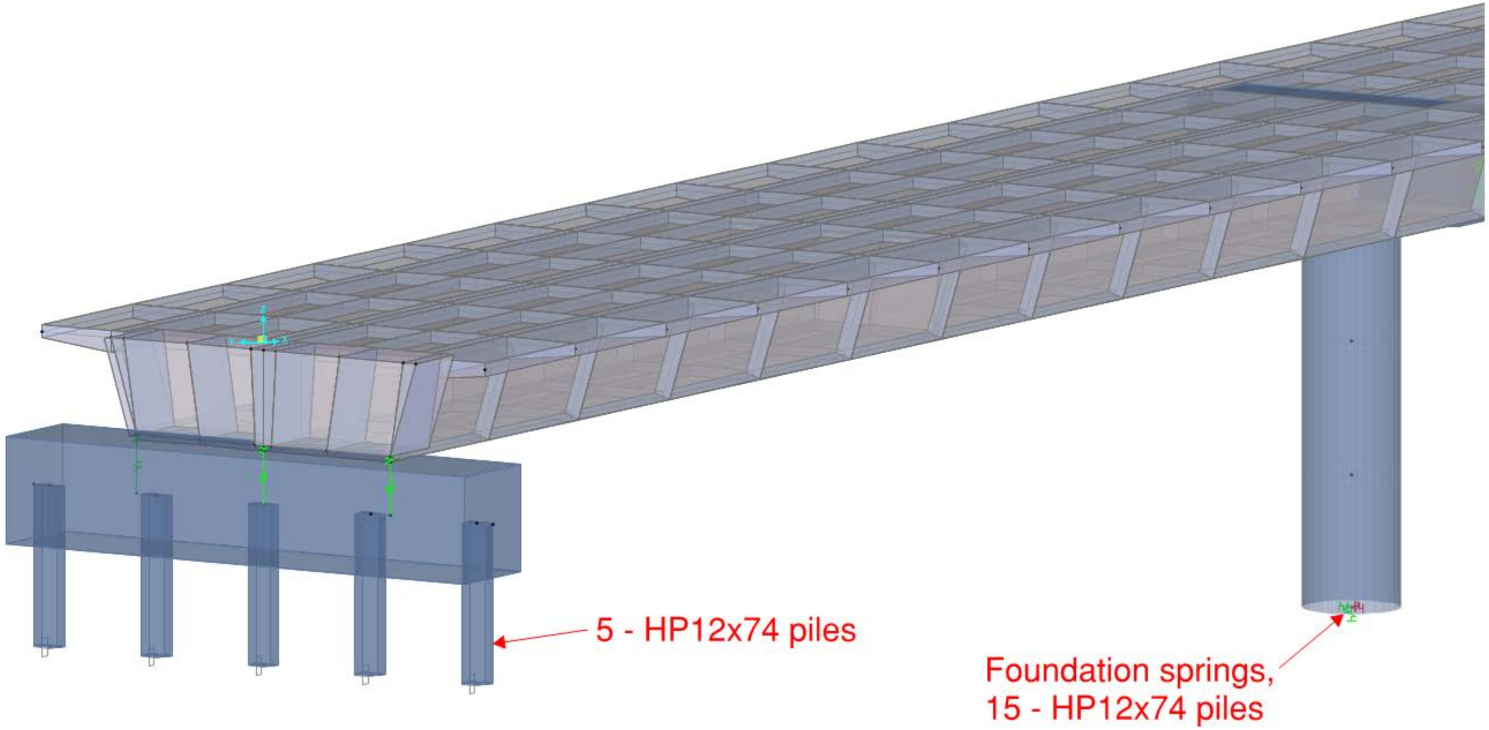
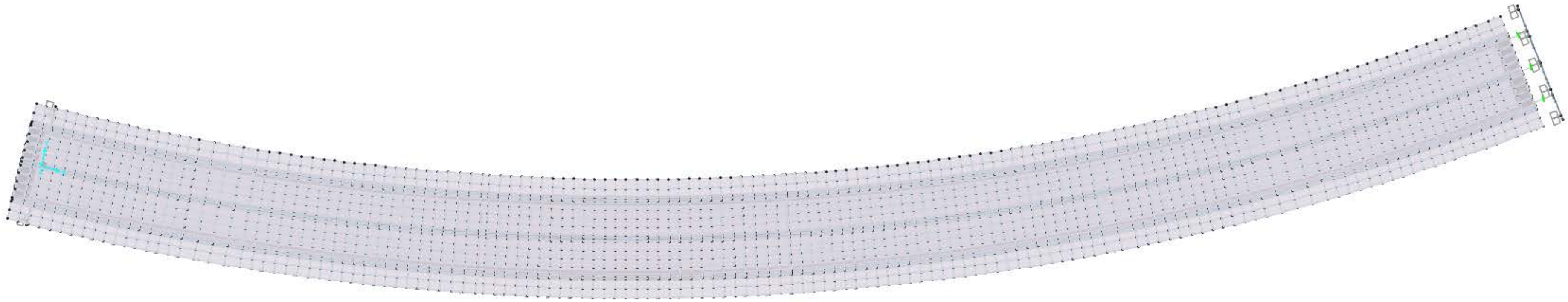
Pile Foundation Model



- Lateral pile stiffness estimated to be 27 kip/in
- Group effects not considered

First Mode: T = 0.82 sec



- **Mode Participation Factor = 0.0791**

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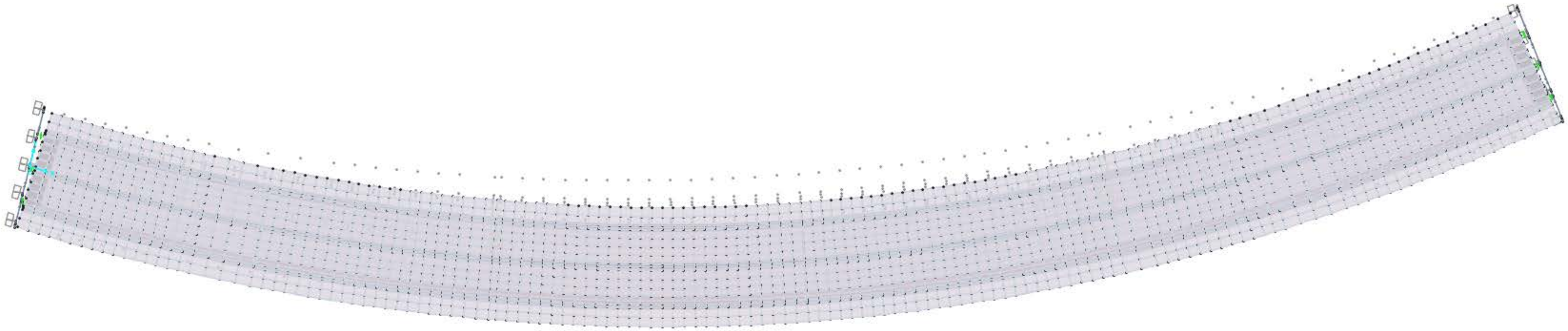
Second Mode: T = 0.76 sec



- **Mode Participation Factor = 0.7293**

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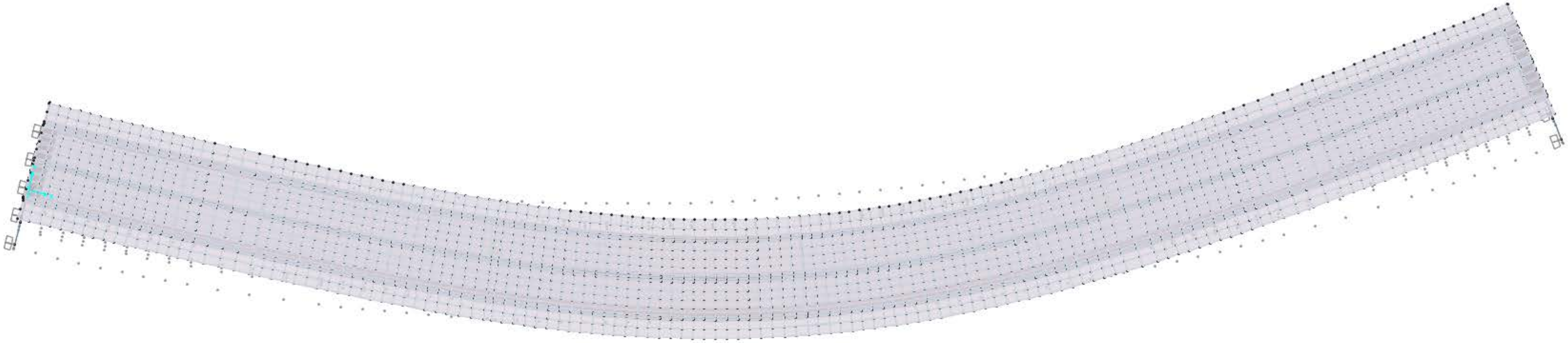
Ninth Mode: T = 0.21 sec



- **Mode Participation Factor = 0.1916**

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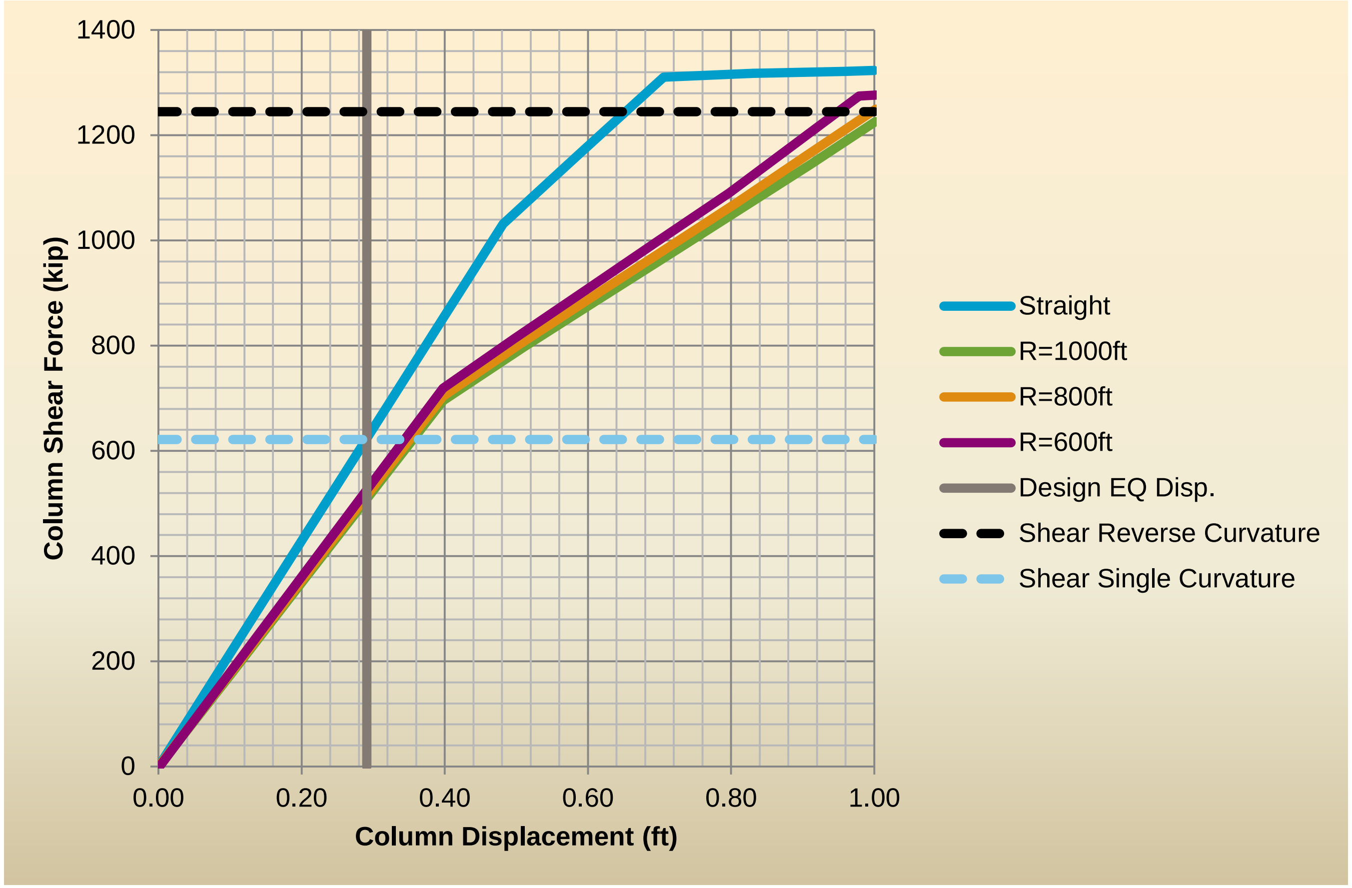
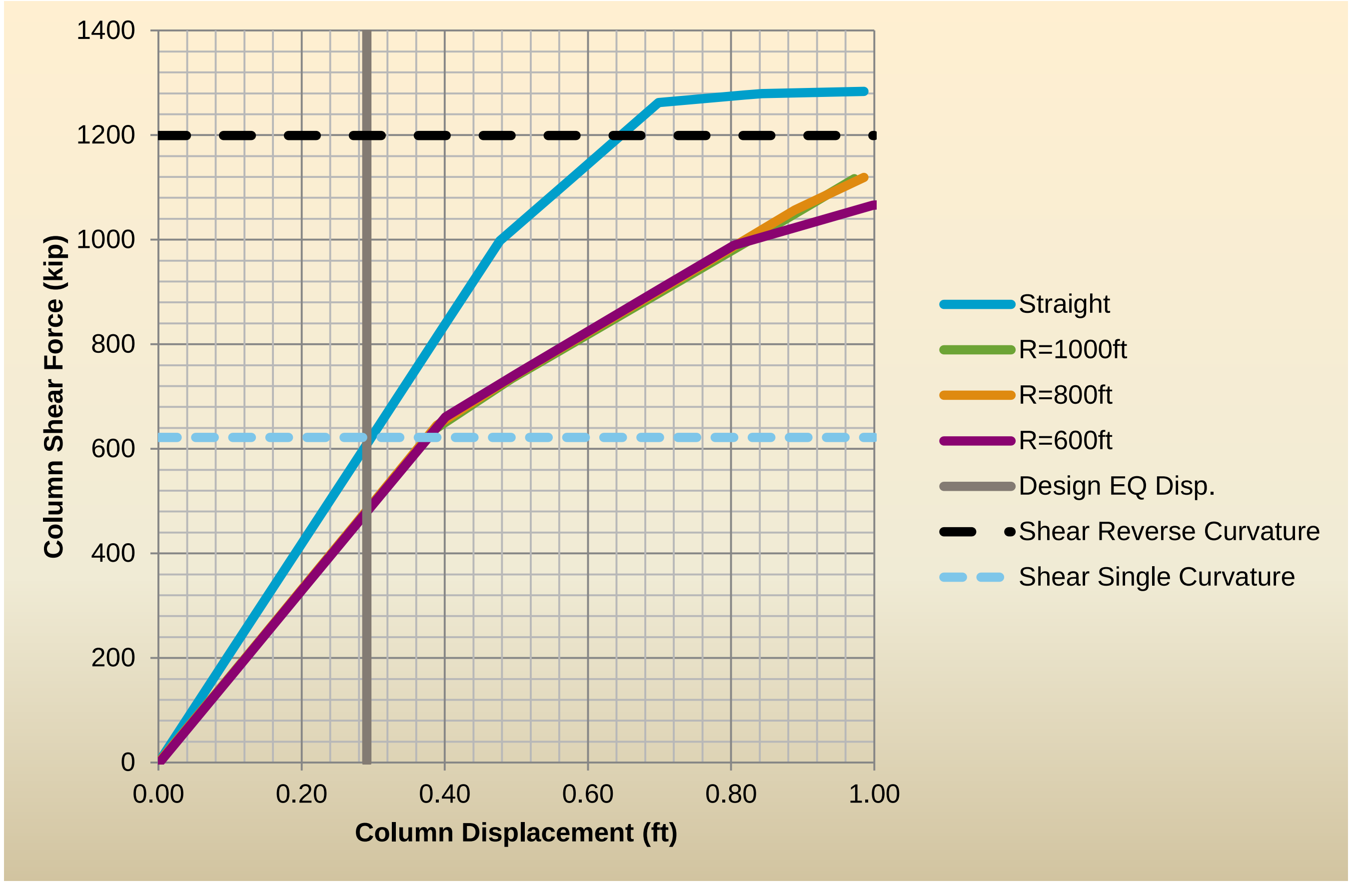
Pile Foundation Response – Pier 1



Pile Foundation Response – Pier 2



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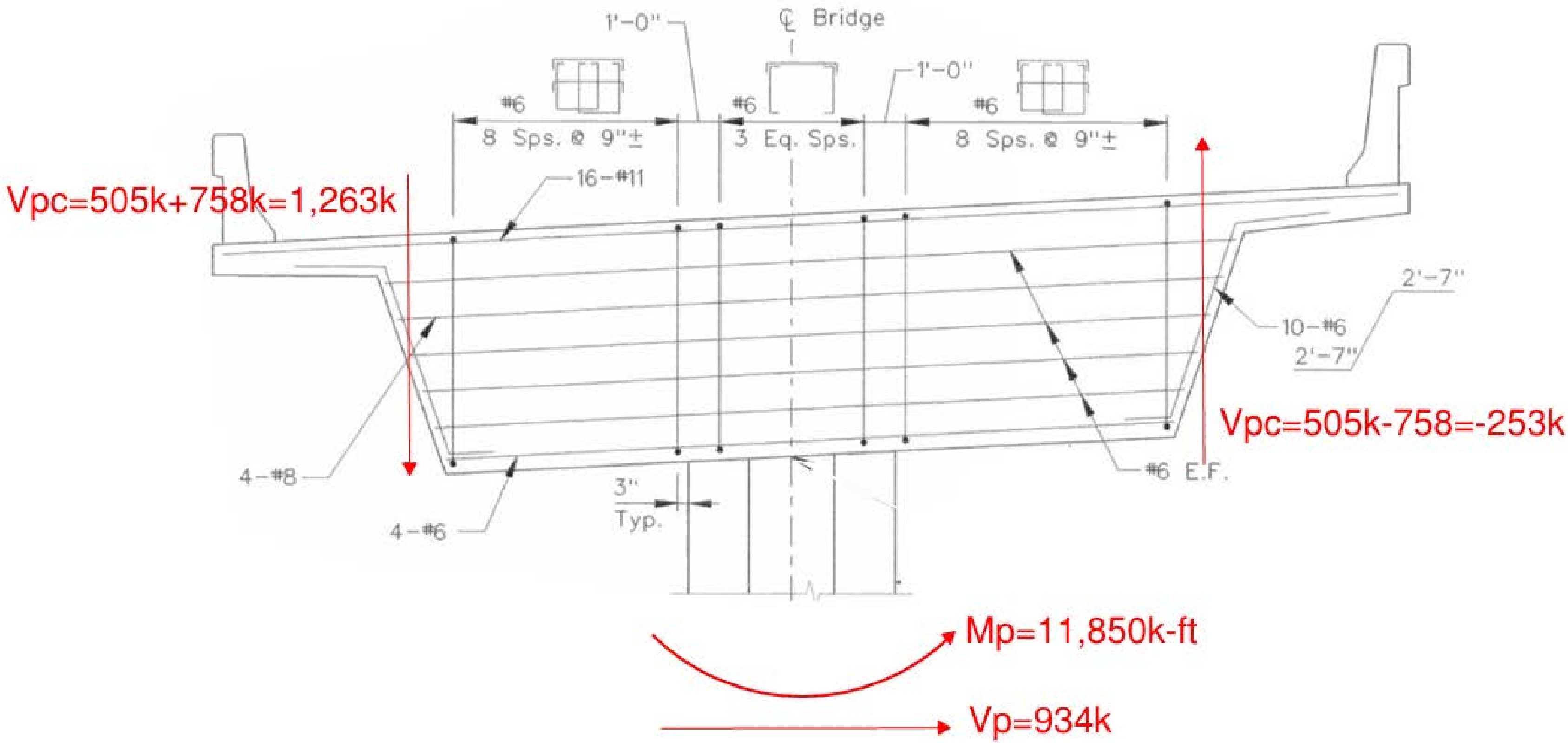
Pier Cap – Free Body Diagram



- **Use S&T model or Conventional Design Procedure**
- **Over-strength factor = 1.0**

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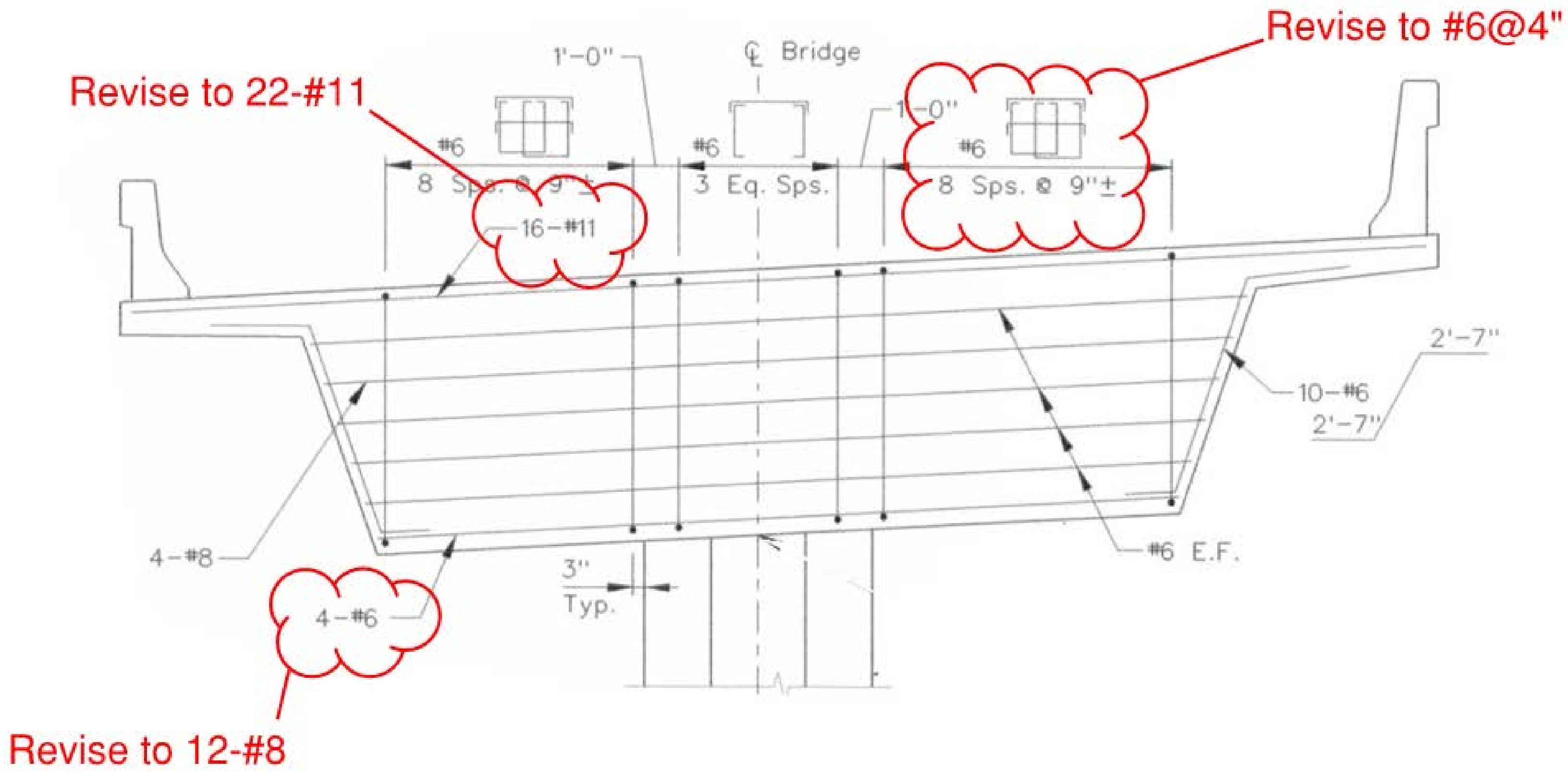
Pier Cap - Revised Design



- **Over-strength factor = 1.2**
- **Strength reduction factor = 1.0**

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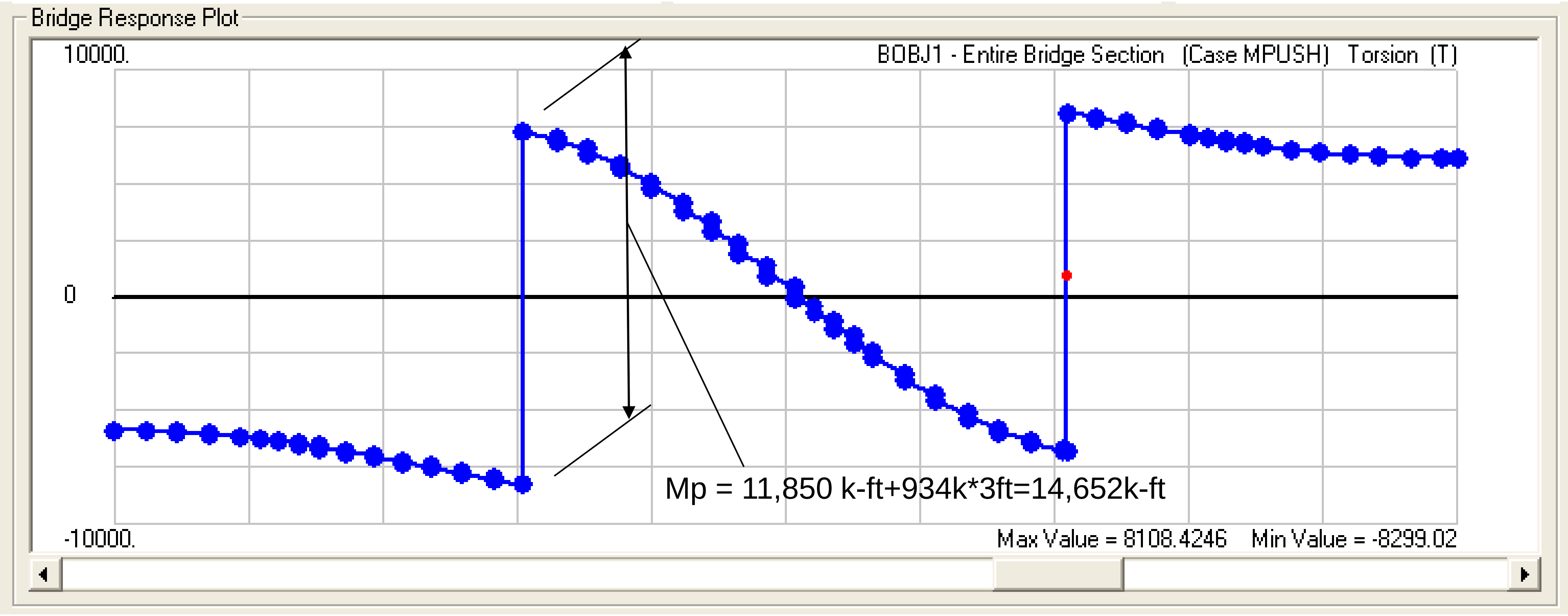
Superstructure Design Checks



- **Check web shear due to plastic hinging induced torsion**
- **Check bearing designs at abutments**

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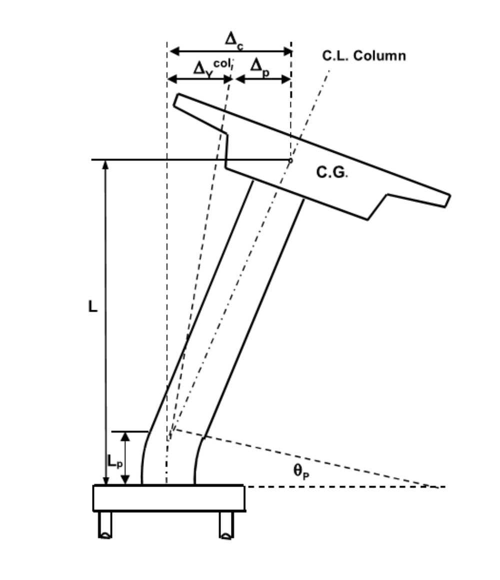
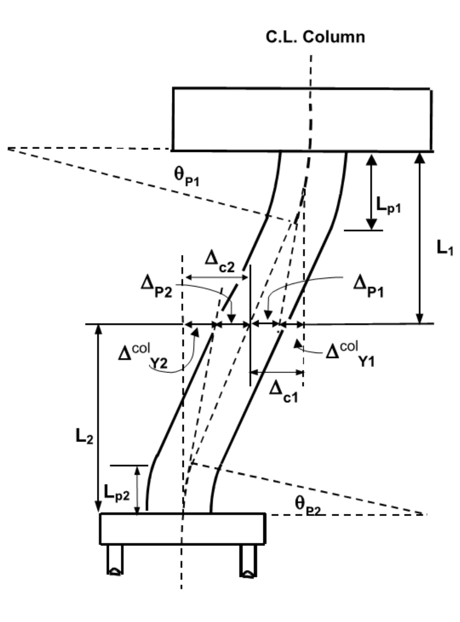
Conclusions

- Hinging is possible at the top of column in the transverse direction due to a combination of superstructure curvature and foundation stiffness.
- Axial load increased up to 10% due to curvature.
- Recommend conducting complete bridge pushover analysis. Distribution of displacements should be based on mode shapes.
- If moment continuity is not provided in the longitudinal direction in a curved bridge, provide appropriate confinement, anchorage details at top of columns. Verify column shear capacity!
- Pier cap and superstructure needs to designed for additional shear due to plastic hinging forces. If in doubt, capacity protect.

Thank You





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